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EFFECTS OF WELD GRINDING ON FATIGUE LIFE OF WELDED JOINTS

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ABSTRACT

Results from a series of fatigue tests of 52 mm thick plate welded T-joints with fully ground welds as per AWS practice are reported. These tests extend the recently completed evaluation of the influence of attachment thickness and improved weld profile on the thickness effect. Lives of joints with fully ground welds are compared with lives of similar joints with welds ground only at the weld toes, according to European practice.

The most significant improvement from weld grinding is obtained at long fatigue lives. The life improvement achieved by full weld profile grinding is comparable to improvement from weld-toe grinding.

LABORATOIRES DE LA TECHNOLOGIE DES MÉTAUX
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EFFETS DU MEULAGE DE LA SOUDURE SUR LA DURÉE DE VIE EN FATIGUE DES JOINTS SOUDÉS

par

O. Vosikovsky

RÉSUMÉ

Les résultats d'une série d'essais de fatigue sur des joints en T soudés dans des tôles de 52 mm d'épaisseur avec les soudures entièrement meulées selon la méthode de l'AWS sont présentés. Ces essais prolongent une étude récente portant sur l'évaluation de l'influence de l'épaisseur du raccordement et du profil de soudure amélioré sur l'effet d'épaisseur. Les durées de vie de joints avec des soudures entièrement meulées sont comparées aux durées de vie de joints similaires avec des soudures meulées seulement à la jonction de la soudure, selon la méthode européenne.

L'amélioration conféré par le meulage de la soudure est plus importante pour les longues durées de vie en fatigue. L'amélioration observée avec le meulage de la soudure au complet est similaire à celle observée avec le meulage de la jonction de la soudure.

INTRODUCTION

A series of five fatigue tests of plate welded T-joints, designed to evaluate the beneficial effects of full-weld profile grinding, as recommended by the AWS Structural Welding Code (D1.1, 1986) for branch members (attachments) thicker than one inch, on fatigue life is reported. This report is an extension to the earlier MTL report (Vosikovsky and Bell 1991) evaluating effects of attachment thickness and improved weld profile achieved by weld bead placement only.

MATERIAL, TEST JOINT GEOMETRY, AND TEST PROCEDURE

The test joints were manufactured from CSA G40.21 WT Grade 350 offshore quality steel. The joint size, designated "C" in Fig. 1, with attachment and base plate thickness equal to 52 mm, was used for fatigue testing.

The full penetration manual welds were prepared with the radius profile fillets roughly equal to 26 mm, half of the attachment thickness. After welding, the weld profiles were ground smooth using a 50 mm diam grinding stone. Care was taken to remove all undercuts and weld toe or in-between pass defects.

Measurements of weld profile radius made on sectioned silicone rubber replicas showed a variation within the 26 ± 2 mm range.

Procedures used in fatigue testing were the same as for previously tested joints (Vosikovsky and Bell 1991). The T-joints were loaded in three point bending with the load applied through the attachment, load ratio $R = 0.05$, and frequencies 2 to 5 Hz.

Fatigue crack growth was again monitored using the AC potential drop technique with 18 spot-welded probes spaced 10 mm apart along the length of the weld. The span of the probes was 10 mm for standard welds with straight fillets. For welds with the ground or controlled AWS profiles where cracks also initiated within the weld, the probe span had to be increased to 25 mm. This reduced the sensitivity of the technique by about a factor of 2.5. The previously estimated capability of the technique to detect a 0.5 mm deep crack located midway between the probes was reduced to a crack depth of over 1 mm.

The ink stains and beach marks were again used to identify the number of initiated cracks, their shape development, and to convert the potential drop measurements into crack depth.

RESULTS AND DISCUSSION

Results from five tests of T-joints with fully-ground welds are summarized in Table 1. The joints are identified by number, weld type, and attachment/base-plate thickness, t/T. The stress ranges are the weld-toe stress ranges calculated using simple beam theory.

The fatigue crack initiation life, N_i, is as previously defined, the number of cycles at the detection crack depth of 0.5 mm. Because the longer probe spans used in this test series result in a deteriorated detection capability, the initiation lives may be overestimated. The total life, Nt, is defined as the number of cycles when the maximum crack depth reaches half of the base plate thickness. The number of fatigue cracks initiated near the weld-toe and within the weld, determined from ink stains, are given separately.

The total lives are presented in S-N plot format in Fig. 2, and compared with data measured earlier on joints with the AWS improved weld profile achieved by controlled welding (Vosikovsky and Bell 1991). S-N curves for 52 mm thick joints with unimproved 45° welds from Phase I of the Canadian Offshore Program (Mohaupt et al. 1987), and from European tests on joints with improved weld profiles achieved by weld-toe grinding as recommended by U.K. Department of Energy 1984 Offshore Code are also included. The S-N curves are identified by the thickness of the tested welded joints. The 50 mm thick joints were tested within the U.K. Offshore Steel Research Project 1987, (UKSORP), the S-N curve for the 38 mm thick joints was reported by Booth 1987, and the results for 30 mm thick joints are from the Norwegian Program, reported by Haagensen et al. 1987.

Comparison of these results shows that the main benefit from weld improvement is obtained at long life. The fatigue limit estimated at 70 MPa for joints with unimproved 45° welds is increased to over 90 MPa for joints with the AWS improved profile, and to over 170 MPa for joints with fully-ground welds. The European results for 50 and 38 mm joints with weld-toe ground welds indicate a similar fatigue limit of 160 MPa. In the shorter life range grinding extended the total life by about five times with the exception of 50 mm joints from UKOSRP which show approximately a three times life extension. The lives of joints with fully-ground welds are only marginally longer than the lives of weld-toe ground joints. Considering the scatter and small number of tests it may be concluded that both grinding methods produce about the same improvement in fatigue life.

The crack initiation lives, plotted in Fig. 3, show twice as much life extension due to grinding than do the total lives. This is expected since the portion of life spend in initiation will increase with the reduced stress concentration at the crack location. The mean N_i/N_t increased from 27% for joints with 45° weld to 33% for joints with profiled AWS weld (Vosikovsky and Bell 1991) and to 61% for joints with the ground welds, Table 1. However, the initiation life increases of joints with profiled welds may be smaller (by an estimated 4-10%) due to the reduced detection capability associated with longer probe spans. Thus the extension of initiation life is significant only for joints with ground welds with a very low stress concentration factor of 1.4 (Vosikovsky and Bell 1991).

The number of initiated cracks (Table 1) increased, in the as-welded joints, with increasing stress range. The single crack-shape development in the joint tested as the 200 MPa

stress range is shown in Fig. 4. The crack started inside the weld at least 5 mm away from the spot welded probes. No defect was observed at the initiation site. The shape development of multiple cracks in the joint tested at 300 MPa is shown in Fig. 5. All cracks again initiated in the weld. The deepest crack in the centre started from a sub-surface pore 0.6 mm in diameter. The remaining cracks initiated from the ACPD probe spot welds, located on the weld. In the joint tested at 250 MPa all cracks initiated from the probe spot welds located on the base plate about 2 mm from the weld-toe.

The initiation of cracks from spot welds had an adverse effect on fatigue life. However, examination of the initiation lives in Fig. 3 shows that joints tested at 200 and 300 MPa (where the first crack initiated far away from spot welds) had the relatively shortest lives. This indicates that any life reduction due to spot welds was likely only marginal.

Figure 6 shows the fatigue crack growth measured by probe over the largest initiated crack in each joint are presented in Fig. 6. Only in the joint tested at 300 MPa did the crack depth increase abruptly from zero to ~2 mm, indicating late detection. For deeper cracks, because of beach-mark depths use for potential calibration, the crack depth measurements are reasonably accurate. There is no explanation for early crack initiation in the joint tested at 200 MPa, since no defect or grinding irregularity was found near the initiation site of the single crack. The single growing crack keeping a high aspect ratio through almost all of its life (Fig. 4) results in a relatively long crack propagation life.

The effects of improved weld profiles, achieved by welding and grinding, on fatigue crack growth at a stress range of 200 MPa are shown in Fig. 7. Weld profiling by controlled welding produces a factor of 1.5 gain in both initiation and total life, while grinding increases the initiation and total lives by factors of 6.8 and 4.4 respectively.

CONCLUSIONS

Based on a small series of fatigue tests of plate T-joints with fully-ground weld profile compared with earlier test results and data from the literature the following conclusions can be drawn:

1. The most significant improvement from weld grinding is obtained at long fatigue lives. The fatigue limit increases from about 80 MPa for a 45° straight weld to approximately 170 MPa for ground welds. In the short life range, the total life is extended by a factor of about five.

2. The fatigue life improvement achieved by grinding of the full profile of the weld, as per AWS recommended practice, is comparable to the improvement from weld-toe grinding recommended by the European practice.

3. The crack initiation life is extended by grinding much more than crack propagation life. The portion of life spent in crack initiation increased from 27% for 45° welds to 61% for ground welds.

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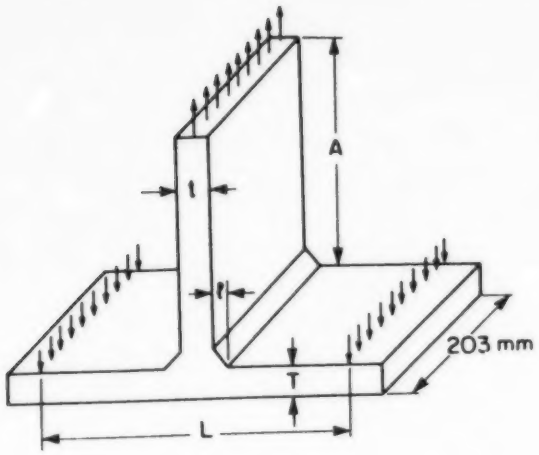
Table 1. Fatigue test results

Joint No. weld profile	t/T mm/mm	Stress range MPa	N_i kcycles	N_t kcycles	N_i/N_t %	Number of cracks	
						Weld toe	Weld
T21C GRD	52/52	300	212	283	74.9	0	12
T20C GRD	52/52	250	337	506	66.6	9	0
T18C GRD	52/52	200	251	600	41.9	0	1
T22C GRD	52/52	175	>6000				
T19C GRD	52/52	150	>6000				



JOINT	T mm	t mm	l mm	L mm	A mm
A	16	16	8-12	300	406
B	26	26	14-18	442	406
C	52	52	26-32	442	406
D	78	78	37-42	584	457
E	102	102	51-58	868	457
F	52	26	14-18	406	406
G	102	26	14-18	868	457

Fig. 1. Geometry and dimensions of tested T-joints. Joint 'C' with weld ground to radius r = t/2 was used.

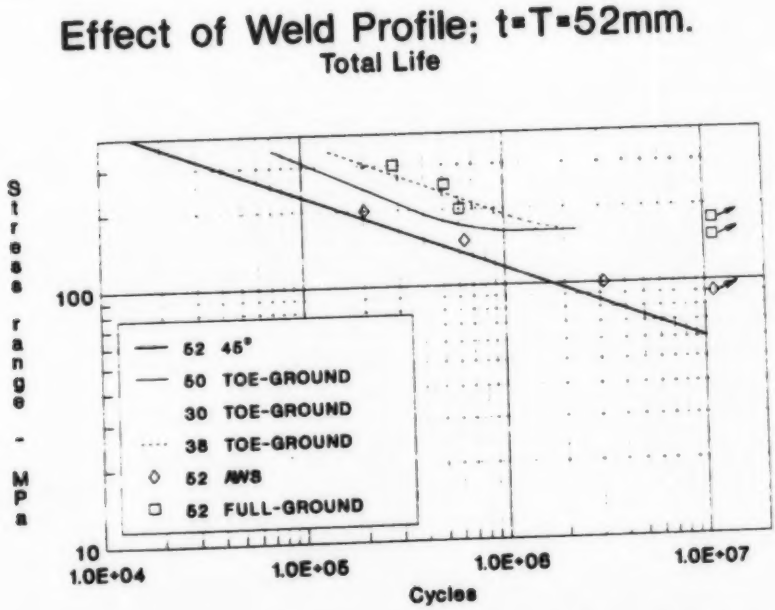


Fig. 2. Total fatigue lives of joints with ground and as-welded improved weld profile, compared with S-N curves for joints with 45° and toe-ground welds.

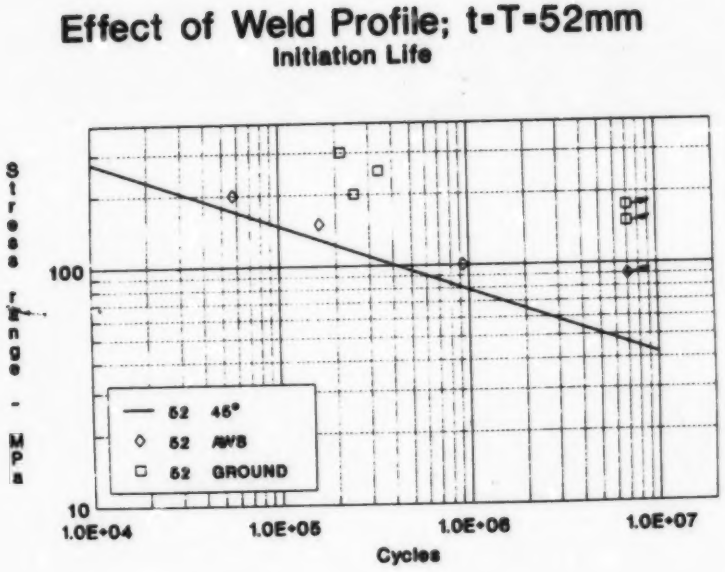


Fig. 3. Crack initiation lives of joints with ground and as-welded improved weld profile, compared with S-N curve for joints with 45° welds.

Fig. 4. Fracture of joint T18C tested at 200 MPa stress range. Ink stain and beach marks outline the crack size and shape development.

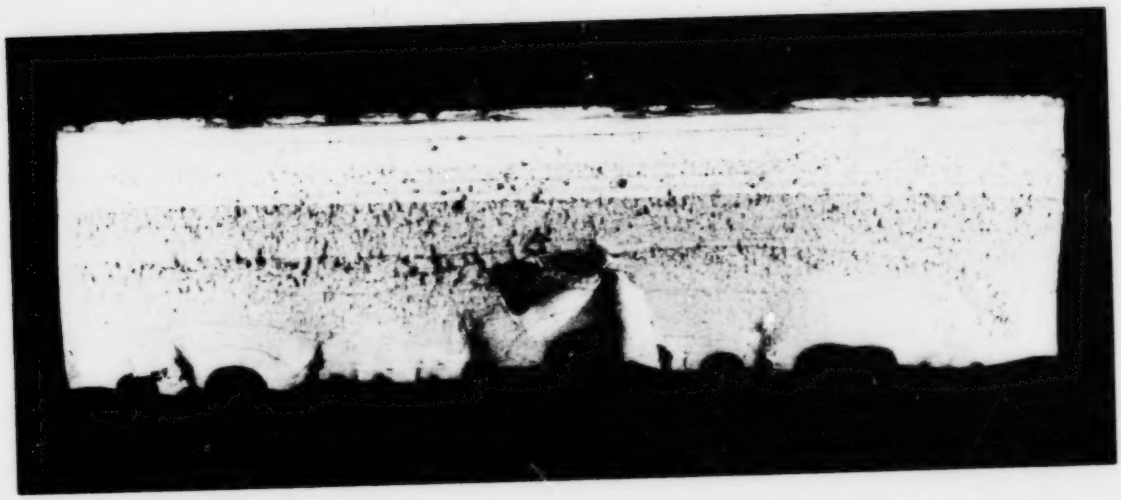


Fig. 5. Fracture of joint T21C tested at 300 MPa stress range. Ink stains and beach marks outline the crack size and shape development.

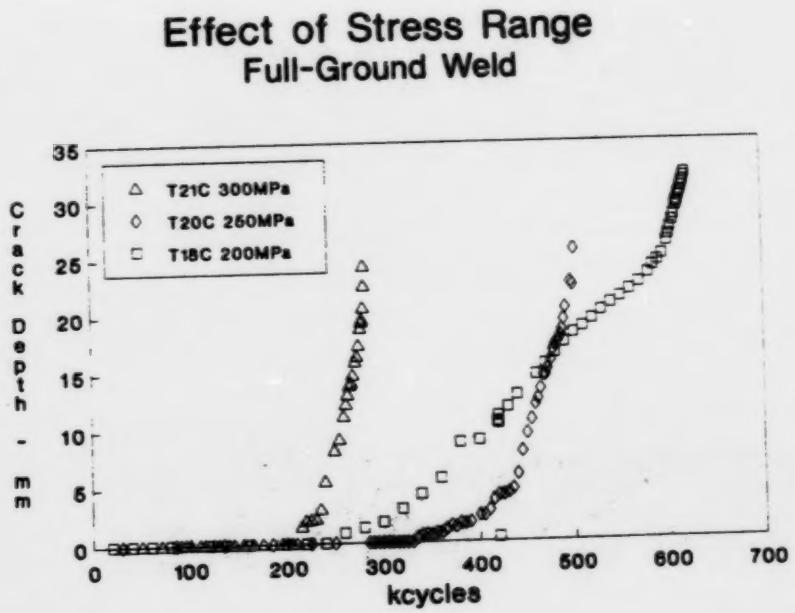


Fig. 6. Growth of the fatigue cracks in joints with ground welds tested at 300, 250, and 200 MPa stress ranges.

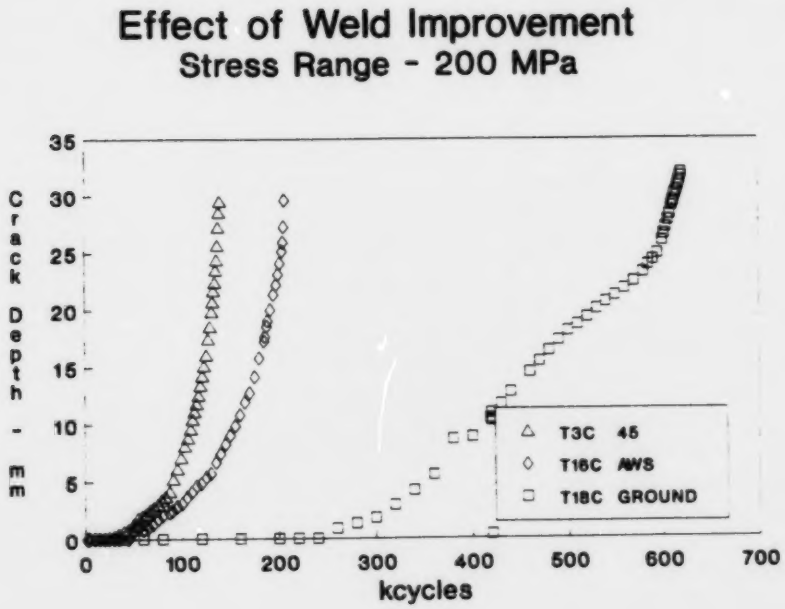


Fig. 7. Growth of the fatigue cracks in joints tested at 200 MPa stress range with 45° welds and improved weld profiles by controlled welding and grinding.